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TITLE

POWER SUPPLY FOR LIGHT EMITTING DIODE ARRAY

BACKGROUND OF THE INVENTION

5 The present invention relates generally to an apparatus for generating power to a light emitting diode array and, in particular, to a power supply for operating light emitting diode array traffic signals.

10 Light emitting diode (LED) arrays are becoming more common in many applications as they are used to replace less efficient incandescent lamps. Status annunciators, message boards, liquid crystal display back lights and traffic signals are common applications for LED arrays. In most of these uses, electrical power is obtained from a.c. mains (120 v.a.c., 60 Hz) and some form of power supply converts the alternating line voltage to d.c., or pulsing d.c., for powering the plurality of LEDs.

15 LEDs typically exhibit forward voltage drops on the order of 1.2 to 2.0 volts when driven at average currents of 20 to 25 ma. For purposes of efficiency, the LEDs are usually connected in series so that a higher power supply voltage can be used to light an array of LEDs.

20 In many applications where a relatively large number of LEDs are necessary to deliver substantial light output, several series strings of LEDs with a ballasting resistor in each string are normally connected in parallel. As shown in the Fig. 1., this traditional circuit arrangement provides some redundancy from single point LED failure, as any "open" LED will only extinguish its own series string leaving the other strings active. Since this relatively simple circuit does not provide any regulation, i.e. the light output varies with varying input voltage, it has been
25 generally superseded by the regulated circuit shown in the Fig. 2. The regulated circuit employs a linear current regulator instead of individual ballasting resistors to maintain a given current through the LED strings. The highly dissipative nature of such linear regulators makes such use questionable in heat sensitive apparatus such as LED signals however. Heat generated by the regulator could exacerbate
30 the deterioration of the thermally sensitive LEDs.

A non dissipative, unregulated power supply for LED signals is shown in Fig. 3, and uses a series capacitor as the current limiting element. Such highly

reactive power supplies exhibit very poor power factors however, and may be disallowed by power utilities.

Several problems are associated with these prior art simple circuit topologies. The input current wave forms are generally badly distorted and the power factor is poor. Reasons for the poor power factor and high distortion relate

This phenomenon is well understood, and plagues many small off line power supplies. Until recently these concerns were essentially disregarded by the electrical power industry because the impact to the power grid was relatively small.

Of course, as larger numbers of these low power appliances are connected to the power grid, the effect is no longer inconsequential. In fact, many utilities are placing limits on permissible power factor and distortion behavior of electrical devices connected to their lines.

LED traffic signals are being retrofitted in place of incandescent lamps primarily because of the energy savings common to LED signals. For example, an 8 inch diameter incandescent signal might consume 67 watts and its LED equivalent 14 watts, or a 12 inch diameter incandescent signal would consume 150 watts while its LED replacement would consume only 28 watts. The dramatic energy savings translate into greatly reduced operating cost, which is an important criterion, as electrical power is becoming more expensive. Also, in many parts of the country, electrical generating capacity is at its limits, and new capacity cannot be added because of environmental concerns. This strong interest in LED signals as an important energy conservation resource is clouded however by the poor power factor performance of commercially available signals.

Power factor (p.f.) is well understood in the electrical engineering community as the ratio of real power to real power plus reactive power, or more conveniently, $p.f. = \cos \theta$ where θ is the angle in electrical degrees of the current - voltage phase offset. That is, in many reactive loads powered by sinusoidal (alternating) current, the voltage and current may be out of phase.

The apparent power that has to be delivered to a given load in volt-amperes (VA) is, therefore equal to the true power consumption of the device in Watts divided by the power factor. For example, an appliance with ^{an} internal

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power consumption of 100 Watts that exhibited a power factor of 0.4, would require $100/.4$ or 250 VA of energy from the power line and utility generator. Taken separately, the many small electrical appliances that are widely used have only a moderate effect on generating capacity. However in aggregate, a large number of small devices can have a significant impact on the power grid.

By means of example, a medium size city (San Francisco) may have some 2000 signalized intersections with a total of 16,000 mixed 8 inch and 12 inch traffic signals. If the existing incandescent signals with an average power consumption of 100 watts are replaced with LED variants of 20 watt rating, a significant power saving should result. The 1600 kilowatt (kW) load imposed by the incandescent signals should be reduced to 320 kw by the LED retrofit devices. However, if the LED signals exhibit an actual power factor of 0.3, the resulting load to the power grid is 320 kW divided by 0.3 p.f. or 1067 kW. The energy savings is then only 533 kW, which is the net amount of power that the utility can convert to other uses. Clearly then, the need for power factors close to unity is apparent. Another factor that directly influences the amount of power (apparent VA) that needs to be delivered to a given load is the total harmonic distortion of the current waveform supplying the device. True power factor is adversely affected by current or voltage distortion, and the significance of this influence is only now being widely accepted. There is shown in the Fig. 4, a traditional power factor vector diagram (which is normally two dimensional) which has been expanded to a three dimensional form to indicate the influence of distortion on the apparent power vector. The total power required vector VA (apparent power) is determined by the combination of the working power vector WATTS, the volt-amperes reactive vector VAR (non-working power) and the distortion volt-amperes vector DVA (non-working power).

Harmonic distortion or deviation from true sinusoidal wave forms not only gives rise to further wasted energy, but increases the electromagnetic interference potential of the load. Radiated and conducted interference is a concern because of the interference potential with other services (radio communications for example).

Harmonic distortion is becoming more prevalent in power supplies as these devices are converted from inefficient linear operation to far more efficient switchmode operation. A wide variety of circuit topologies are used in modern

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switching power supplies such as thyristor and triac phase control, or bipolar or field effect transistor switches. A consequence of these solid state approaches is increased harmonic distortion and poor power factor behavior. In order to mitigate these problems, several approaches to power factor and distortion control have been developed that operate with and use the efficiency of the switchmode power supply itself. That is, instead of correcting for power factor in a separate functional device (that is connected between the power supply and line), the power factor and distortion correcting function is part of the switchmode power supply. A number of manufacturers of integrated circuits (Linear Technology, Silicon General, Motorola and Unitrode for example) offer monolithic devices that perform the power factor and distortion control function. A review of this art is presented in *Power Supply Cookbook* by Marty Brown, 1994, Butterworth-Heinemann.

SUMMARY OF THE INVENTION

The present invention concerns an apparatus for supplying regulated voltage d.c. electrical power to an LED array. The apparatus includes a rectifier having an input and an output, the rectifier being responsive to a.c. power at the input for generating rectified d.c. power at the output, a power factor correction converter having an input connected to the rectifier output and an output, the power factor correction converter being responsive to the rectified d.c. power at the power factor correction converter input for generating regulated voltage, d.c. power at the power factor correction converter output, and an LED array having an input connected to the power factor correction converter output for receiving the d.c. power to illuminate the LED array. The power factor correction converter can be a power factor correcting and voltage regulating buck/boost switchmode converter.

A primary object of the present invention is to provide a power factor correcting, (boost, buck/boost or buck) switchmode converter to power a line operated LED signal.

Another object of the present invention is to use the inherent pulse modulating nature of a switchmode power supply to provide voltage regulation to an LED array.

The apparatus according to the present invention also includes an adaptive clamp circuit connected to the rectifier input for eliminating leakage current

problems. The adaptive clamp circuit has an input adapted to be connected to a pair of a.c. power lines, a pair of clamp circuit output lines connected to the adaptive clamp circuit input, a voltage sensing means connected across the adaptive clamp circuit input, and a controlled load means connected across the clamp circuit output lines and to the voltage sensing means. The voltage sensing means is responsive to a magnitude of a.c. voltage at the adaptive clamp circuit input lower than a predetermined magnitude for turning on the controlled load means to connect a low impedance load in the controlled load means across the clamp circuit output lines and the voltage sensing means is responsive to a magnitude of the a.c. voltage at the adaptive clamp circuit input equal to or greater than the predetermined magnitude for turning off the controlled load means to disconnect the low impedance load from the clamp circuit output lines.

It is also an objective of the present invention to eliminate leakage current problems by providing an adaptive clamp circuit.

Another feature of the present invention is to provide an adaptive line loading means or clamp that switches itself in or out of the circuit as needed.

The apparatus according to the present invention further includes a battery backup system having an input for receiving a.c. power applied to the rectifier input and having an output at which d.c. power is generated, and a switch-over relay connected to the battery backup system output and to the rectifier input, the battery backup system being responsive to a failure of a.c. power at the battery backup system input for controlling the switch-over relay to connect the battery backup system output to the rectifier input to provide d.c. power to illuminate the LED array and being responsive to a.c. power at the battery backup system input for controlling the switch-over relay to disconnect the battery backup system output from the rectifier input.

Another object of the present invention is the use of a d.c. power supply (instead of the a.c. power line) as a power backup that is activated upon a.c. power line loss.

BRIEF DESCRIPTION OF THE DRAWINGS

The above, as well as other advantages of the present invention, will become readily apparent to those skilled in the art from the following detailed description

of a preferred embodiment when considered in the light of the accompanying drawings in which:

Fig. 1 is a schematic diagram of a prior art unregulated power supply for LED signals;

5 Fig. 2 is a schematic diagram of a prior art linear current regulated power supply for LED signals;

Fig. 3 is a schematic diagram of a prior art reactively ballasted power supply for LED signals;

10 Fig. 4 is a three dimensional vector diagram of the total power required to operate an LED array;

Fig. 5 is a schematic diagram of a regulated voltage, switchmode power supply for LED signals in accordance with the present invention;

Fig. 6a is a schematic block diagram of the adaptive clamp circuit shown in the Fig. 5;

15 Fig. 6b is a schematic diagram of the adaptive clamp circuit shown in the Fig. 6a; and

Fig. 7 is a schematic block diagram of a battery backup system for LED signals according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

20 As noted above, the elementary power supplies that are currently used for powering LED array signals do not meet current standards for efficiency, reliability and performance. The unregulated, resistively ballasted power supply shown in the Fig. 1 does not isolate the LEDs from line voltage variations, and exhibits a poor power factor because of the rectifier and large capacitor. The commercially
25 produced current regulated LED power supply, which is shown in the Fig. 2, does provide much better LED light intensity regulation with input voltage variation. However, the use of a linear, dissipative (heat producing) regulator presents problems. LEDs are thermally sensitive devices which degrade quickly at elevated temperatures. Since most power supplies for LED signals are part of, or are
30 attached to the LED array, heat rise from the linear regulator can be deleterious. Furthermore, the traditional rectifier-capacitor circuit does not produce a satisfactory power factor.

The use of capacitors as non-dissipative current limiters in a.c. circuits is well established, and is shown in the Fig. 3 as another example of a commercially available LED array signal power supply. Current and voltage wave forms are essentially out of phase in this type of circuit, so that heat is not generated in the current limiting capacitor (15 μ F). However, the power factor and distortion performance of this type of circuit is very poor (P.F. \approx 0.3).

There is shown in the Fig. 5, a regulated voltage, switchmode power supply 10 according to the present invention connected to an LED array 12. The LED array 12 includes a plurality of strings of series connected LEDs 14 with a ballasting resistor 16 (R1, R2, R3, R4, R5, ...) connected in each string. The strings are connected in parallel between a first input line 18 and a second input line 20 of the LED array 12.

The power supply 10 has a pair of power input lines 22 for connection to a source (not shown) of a.c. power such as main power lines at a nominal 120 volts a.c. An input of an adaptive clamp circuit 24 can be connected to the lines 22 as an option. A problem peculiar to signals that are switched by means of solid state relays is the leakage current that can flow through the load when the solid state switch or relay is "OFF". This phenomenon is common to triac and thyristor switches that are commonly employed in traffic signal controllers. While not apparent when incandescent signals are employed (because they are low impedance loads), the problems surface when relatively low power loads (such as LEDs) are connected to these same controllers. Typically, other safety devices used in traffic signal controllers such as conflict monitors must be "tricked" to reduce this leakage current. Commonly, a large capacitor is placed across the a.c. input leads to the LED load, in order to absorb the leakage current reactively. Of course, such provisions only aggravate the power factor problems.

An output of the adaptive clamp circuit 24 is connected by a pair of clamp circuit output lines 26 to an input of an electromagnetic interference (E.M.I.) filter 28. The E.M.I. filter 28 keeps conducted interference from feeding back into the power lines where it might cause problems to other circuitry on the line. An output of the filter 28 is connected by a pair of filter output lines 30 to an input of a

rectifier means **32** which converts the incoming a.c. power to a pulsing d.c. power generated on a positive polarity rectifier output line **34** and a negative polarity rectifier output line **36**. Although the rectifier means is shown as a full wave diode bridge rectifier, any type of rectifier can be used. The lines **34** and **36** are connected to an input of a power factor correction, buck/boost converter **38**. The converter **38** includes a power factor correction (P.F.C.) integrated circuit (I.C.) controller **40**, which is a commercial device available from many sources and functions by allowing current to charge a storage capacitor **C (LARGE)** only in phase with the rectified a.c. voltage thereby assuring a power factor close to unity.

10 The control I.C. **40** also provides voltage regulation in the switchmode buck/boost converter by monitoring the output voltage and adjusting the high frequency on-off switching period of the pass element commensurately. Although a buck/boost converter is diagrammed, buck or boost topologies are also possible. Voltage output and current-mode control techniques are the primary differences in the various geometries, but these details are incidental to the functionality of the circuit.

15 A positive polarity output of the converter **38** is connected by a positive polarity converter output line **42** to the first input line **18** of the LED array **12**. A negative polarity output of the converter **38** is connected by a negative polarity converter output line **44** to the second input line **20** of the LED array **12** through an optional pulse width modulated (P.W.M.) modulator **46**.

20 The output voltage from the P.F.C. switch mode converter **38** is either fed directly to the LED array **12**, or alternatively through the P.W.M. modulator **46**. Such pulse modulation has been shown to be advantageous in certain LED signal applications. The functions of the switchmode P.F.C. converter **38** as the off line power supply are the same irrespective of the load. The obvious advantage of using a switching, voltage regulated power supply is efficiency. Line isolation, which is generally not provided by this transformerless design, is generally unnecessary for insulated LED signals, but a high frequency transformer could be incorporated. The intrinsic power factor correction provided by using the

30 switchmode converter **38** in conjunction with the P.F.C. integrated circuit controller **40** is not only cost effective, but allows d.c. backup power to be used in case of line failure.

A primary aspect of the present invention is the use of a power factor correcting, (boost, buck/boost or buck) switchmode converter to power a line operated LED array signal 12. Another function of the present invention is to use the inherent pulse modulating nature of the switchmode power supply to provide voltage regulation to the LED array signal 12. Instead of using dissipative (heat producing) linear regulators for either voltage or current (to accommodate line voltage variations), the power factor and distortion controlling switchmode power supply 10 is used as an efficient voltage regulator. That is, the LED array 12, consisting of a large number of series-parallel connected LED devices 14, can be kept at essentially constant luminosity over a substantial range of input voltages. In actual practice, the output of such LED array signals has been kept within $\pm 10\%$ of nominal value over a power line variation of 85 volts to 140 volts (for a nominal 120 v.a.c. line).

It is also an objective of the present invention to eliminate leakage current problems by providing the adaptive clamp circuit 24 which is shown in more detail in the Figs. 6a and 6b. The power input lines 22 are connected directly through the adaptive clamp circuit 24 to the clamp circuit output lines 26. The adaptive clamp circuit 24 monitors the input voltage feeding the LED array 12 on the input lines 22 with a voltage sensing means 48 connected across the lines 22 and loads the input lines resistively with a low impedance controlled load means 50, connected across the output lines 26, whenever the line voltage is below some critical amount (typically 40 volts a.c. r.m.s.). The adaptive clamp circuit 24 assumes that voltages lower than a certain value (typically 40 volts) are due to leakage currents through the solid state control relay or switch. The adaptive clamp circuit 24 loads the lines with a resistor to draw current, forcing the leakage voltage to a lower voltage (typically on the order of 10 volts a.c.) that will not cause problems for the conflict monitor or power factor correction (p.f.c.) circuit. Most traffic signals must be capable of being flashed (at least the red and yellow signals) from the traffic controller electronics. It has been found experimentally that residual leakage currents interfere with the ability to flash signals that are equipped with power factor correction circuits. The adaptive clamp circuit 24 prevents this problem by allowing the p.f.c. circuit to completely discharge between power line

pulses which flash the signal at a nominal sixty flashes per minute. In summary, the adaptive clamp circuit **24** performs two functions by reducing the leakage voltage: 1) it provides a reactance free means to eliminate problems with conflict monitors (while preventing poor power factors); and 2) it allows the p.f.c. circuit

5 to properly flash the LED array signal **12**.

The adaptive clamp circuit **24** is shown in more detail in the Fig. 6b wherein a first pair of diodes **D3** and **D4** has anodes connected to the lines **22** and cathodes connected together. A second pair of diodes **D1** and **D2** has cathodes connected to the lines **26** and anodes connected together. A first resistor (**R1**) **52**

10 is connected between the junction of the second pair of diodes **D1** and **D2** and an anode of a Zener diode **D5**. The Zener diode **D5** has a cathode connected to the junction of the first pair of diodes **D3** and **D4**. A second resistor (**R2**) **54** is connected between the anode of the Zener diode **D5** and a base of a first NPN transistor **Q1**. The transistor **Q1** has an emitter connected to the junction of the

15 second pair of diodes **D1** and **D2** and a collector connected through a third resistor (**R3**) **56** to the junction of the first pair of diodes **D3** and **D4**. A fourth resistor (**R4**) **58** is connected between the collector of the transistor **Q1** and a base of a second NPN transistor **Q2**. The transistor **Q2** has an emitter connected to the junction of the second pair of diodes **D1** and **D2** and a collector connected through

20 a fifth resistor (**R5**) **60** to the junction of the first pair of diodes **D3** and **D4**.

The optional adaptive clamping circuit **24** is advantageously placed across the input terminals of the p.f.c., switchmode power supply **10** as shown in the Fig. 5. As noted above, as a consequence of using solid state relays or switches in signal controllers, the power to the signals is not fully disconnected (even when the

25 signal should be off). This leakage current often causes problems with safety devices such as electronic conflict monitors. Additionally, these leakage currents may present problems during flashing operation of LED signals, as the power supply circuits may not be fully discharged between flashes. Switchmode, p.f.c. power suppliers of the type proposed for the present invention are particularly

30 sensitive to such leakage currents and will be inhibited from flashing LEDs at an acceptable rate (55 to 60 flashes per minute).

In current practice, these leakage currents are minimized by "short circuiting" them by means of a reactive, non dissipative element. The input capacitor (typically 1-2 μ F), as shown in the Fig. 3 for example, performs this function. However this same capacitor is across the line when the LED array
5 signal is energized, drawing reactive power and contributing to a poor power factor.

Another feature of the present invention is to provide for an adaptive line loading means or clamp that switches itself in or out of circuit as needed. As shown in the Fig. 6b, the adaptive clamp circuit **24** monitors the line voltage, and
10 when only leakage currents are present that drop the line voltage to about 40 v.a.c., the circuit applies a resistive load **60** across the lines **22** by turning on the solid-state switch **Q2**. When the lines **22** are loaded by the fifth resistor **60**, having a suitable value (typically 1 kOhm), the leakage voltage will drop to under 10 volts. At this depressed voltage, the p.f.c. switchmode converter is fully off, and can
15 properly flash the LEDs **14** at the requisite rate.

This adaptive clamp **24** can of course be used with other types of power supplies where the addition of reactive elements could degrade the power factor. The clamping circuit **24** works by using the sensing transistor **Q1** and the Zener diode **D5** (the voltage sensing means **48** of the Fig. 6a) to determine if the line
20 voltage is below a certain magnitude (typically 40 volts). The sensing transistor **Q1** and the Zener diode **D5** are the voltage sensing means **48** of the Fig. 6a. If the Zener diode **D5** does not conduct, the transistor **Q2** is turned on to place the load resistor **60** the power lines **22** causing the leakage voltage to drop below 10 volts. The transistor **Q2** and the resistor **60** are the controlled load means **50** of the Fig.
25 6a. Whenever the traffic signal controller relay "closes", the line voltage appearing at the input to the adaptive clamping circuit **24** rises to nominally 120 volts and the sensing circuit (**Q1** and **D5**) turn off the controlling transistor **Q2**, removing the resistor **60** from the circuit thereby preventing unnecessary dissipation of power. Since there are no reactances involved, this circuit does not influence the power
30 factor reflected at the a.c. input lines **22**.

Another aspect of the present invention is the use of a d.c. input (instead of the a.c. power line) as a power backup feature that is activated upon power line

loss. Conventional practice employs battery driven a.c. inverters to generate the backup power upon line failure. Such inverters are expensive, inefficient and are failure prone. The use of battery power (d.c.) to directly energize the regulated switchmode power supply that powers the LED array signal is very cost effective and energy efficient. The wide input voltage range of most switchmode power supplies allows the batteries to be used optimally as they can be virtually fully discharged in the power backup cycle yielding very good use of battery capacity. Lower cost, smaller batteries are therefore useable.

As noted previously, the use of a direct line operated, non-transformer isolated converter to power the LED array signal allows d.c. power to be used (instead of a.c.) in case of line failure. Using batteries without having to rely on an inverter to perform the d.c. to a.c. conversion is novel, extremely reliable, and cost effective. The importance of battery backup for critical traffic signals is obvious, and the need for reliability is also apparent. As shown in the Fig. 7, a battery backup system 62 includes a temperature compensated, line powered automatic battery charger 64 having an input connected to the lines 22 and an output connected to an input of a rechargeable battery 66 to keep the battery fully charged at all times that a.c. power is available. Temperature compensation can be used to stop the charging process to extend the life of the battery, as it is well known that the optimal end point charging voltage for most secondary cells is a function of temperature.

Because of the critical safety nature of these devices, an automatic battery testing circuit and load 68 is built into the battery backup system 62. Deterioration of the battery 66, which is inevitable over time, is thereby monitored and degradation past a certain point is flagged or announced. The testing circuit 68 has an input connected to an output of the battery 66 for sensing battery voltage. An alarm signal line 70 is connected to an output of the circuit 68 for generating the alarm signal and a set flag signal line 72 is connected to another output of the circuit 68 for generating the set flag signal. A control line 74 is connected between an output of the circuit 68 and an input of the battery 66. Secondary batteries that are kept in float service for any length of time tend to degrade and loose capacity. This deterioration is far more apparent in high temperature environments,

and can adversely affect the safety margins of the backup power supply. That is, instead of providing 8 to 10 hours of flashing red LED array signal backup service, a degraded battery might only last a few hours. Determining the actual condition or serviceability of a storage battery is difficult, because a measurement of terminal
5 voltage does not necessarily indicate loss of capacity. It has been experimentally determined that a good measure of battery capacity can be made by loading the battery with a substantial current (typically 5-10 amperes) for several minutes and measuring the terminal voltage under load. Naturally the battery charger is inhibited during this test. This method is well recognized as a good diagnostic test
10 as it depletes any "surface charge" on the electrodes and more accurately indicates remaining battery ampere-hours.

A voltage comparator circuit in the battery testing circuit and load **68** establishes an "accept" or "reject" level for the battery **66** as it is tested every 24 hours or so. In order to accommodate partly discharged cells, two sequential,
15 battery tests that result in a "reject" are registered in a latch which may trigger a visual or audible alarm signal on the line **70**. Alternatively, a relay or contact closure (flag) may be set to generate a signal on the line **72** so that a data modem can relay the degraded battery information to a central service facility. Of course, such calls or alarm signals are triggered well before the battery is no longer
20 serviceable so that safety is not comprised.

A line failure detection circuit **76** has an input connected to the power lines **22** and another input connected to an output of the battery **66** to receive operating power from the battery. The circuit **76** initiates the power switch-over process whenever a.c. input power is disconnected. An output of the line failure detection
25 circuit **76** is connected to an input of a time delay and restoration circuit **78** which has another input connected to an output of the battery **66** to receive operating power from the battery. The time delay function ensures that short, transient line dropouts are disregarded. An output of the time delay and restoration circuit **78** is connected to an input of a d.c. power switch-over and flasher circuit **80** which
30 has another input connected to an output of the battery **66** to receive operating power from the battery. Outputs of the circuit **80** are connected to a first set of input terminals of a switch-over relay **82**. The relay has a second set of terminals

connected to red signal outputs of a traffic controller **84** having an input connected to the power lines **22**. Output terminals of the switch-over relay **82** are connected to the input of the switchmode converter power supply **10** which is connected to the red LED array signal **12**. Normally, the switch-over relay **82** is in the position shown to connect a.c. power on the lines **22** through the traffic controller **84** to the power supply **10**.

Generally, line loss in excess of 250 msec will cause the d.c. power switch-over relay **82** to switch the output terminals to disconnect the power supply **10** and the red LED array signal **10** from the traffic controller **84** (and the a.c. feed) and connect them to the d.c. battery **66** through the d.c. power switch-over and flasher circuit **80**. Note that the d.c. supply is flashed or pulsed by the circuit **80** at a nominal rate of 60 pulses per minute (1 Hz) to place all the red LED array signals at an intersection in a flashing mode, effecting a four way stop. While an electromechanical switch-over relay **82** is shown for complete isolation of the existing traffic controller **84** and the battery backup system **62**, solid state devices could be used.

Whenever the line power is restored, the time delay and restoration circuit **78** will wait some period (typically 10-15 seconds) before the LED array signal **12** is switched back to the a.c. power mode. This delay avoids the many transients that usually accompany a.c. line restoration after a power outage. Note that no inverter is employed in this system, as is common practice in existing commercial hardware. The inefficiency and poor reliability of d.c. to a.c. converters is thereby avoided. Because the switchmode power supply **10** can accommodate wide variations in input voltage (both a.c. and d.c.) the storage battery **66** can be discharged virtually completely while maintaining essentially constant luminosity of the LED array signal **12**.

Additionally, as shown in the Fig. 7, there are provisions for the introduction of narrow "marker pulses" superimposed on the d.c. supply for use as synchronizing pulses. An optional synchronizing pulse generator **86** has an output connected to an input of the d.c. power switch-over and flasher circuit **80** for generating such pulses. This optional feature permits a number of LED array signals that are pulse modulated to operate in sync in the absence of the 60 Hz a.c.

line signal. These "marker pulses" are essentially short (200 μ sec) power dropouts that do not affect the operation of the LED array signal 12, but are easily extracted at the signal to effect pulse synchronization of several pulsed LED array signals.

- As noted above, the lack of input transformers or series capacitors before the full wave bridge, allows d.c. power to be applied at the input terminals of the power supply 10 in lieu of a.c. power. Since there are no reactive (a.c.) components in the input circuitry, proper operation of the switchmode converter is maintained, and output voltage regulation is still available. Obviously, the p.f.c. portion of the circuit 10 will be nonfunctional during operation on d.c. input power.
- As shown, the switchmode converter will provide an essentially constant output voltage (nom. 100 volts d.c.) to the LED array 12 over a range of a.c. input voltages from 85 volts r.m.s. to 140 volts r.m.s. and over a d.c. input voltage range of 38 volts d.c. to 65 volts d.c. The wide (input voltage) operating range allows rechargeable batteries to be used very efficiently, since their capacity can be fully utilized in the discharge cycle, as their terminal voltage drops.

- As discussed above, LED signals are being used to replace incandescent lamps in many applications. Traffic signals are among the more common devices that are being upgraded for with LEDs because of the tremendous power savings and the dramatic improvement in service life. In most cases the incandescent lamps are merely replaced with an integral LED retrofit assembly that does not require any modification of the existing traffic signal housing or the drive and control circuitry associated with the signal. That is, users expect the LED retrofit lamps to operate normally without added modifications to the housing or traffic controller.

- One aspect of this conversion to LED signals from incandescent lamps poses significant problems however. Many existing incandescent lamp traffic signals are dimmed at night to reduce glare and, of course, power consumption. LED signals can be dimmed by reducing the average current through the LED array. A problem arises however because existing traffic signal controllers dim incandescent signals by providing half-wave rectified a.c. to the devices. Normally the traffic lamps are powered by switched a.c. line power which has, in virtually all cases, a sinusoidal wave form. Simply rectifying this power allows the traffic signal controller to reduce the average voltage and current to the load in a loss free

manner. This technique has been in common use for many years and has become the "defacto" standard dimming technique.

5 Most LED traffic signals do not work satisfactorily with half wave rectified a.c.; in fact, many simply do not light. Some LED lamp arrays which are equipped with regulated power supplies will illuminate satisfactorily when powered by half wave rectified a.c. current, but they do not dim. The regulated power supplies accept the half wave rectified a.c. line power and treat it merely as a low line voltage and correct for this phenomenon. The voltage impressed across the LED array is kept relatively constant in spite of such input voltage variations
10 thereby keeping the LED luminous output essentially unchanged, i.e. undimmed.

Certain switchmode, regulating power supplies are able to power LED signals satisfactorily from even half wave rectified a.c. power supplies. A half wave detector circuit in the LED signal power supply can determine whether the traffic signal controller is sending a "dimming" command. Upon detection of this
15 half wave signal, the switchmode power supply can be programmed or adjusted to reduce its output voltage to the LED array. By adjusting either the pulse width or the frequency (at constant pulse width) of the switchmode power supply, the output voltage (and/or current) can be reduced in an efficient, nondissipative manner.

Alternatively, the half wave detector can be used to change the average
20 current through the LED array by reducing the effective pulse width of a pulse width modulation controller that drives the LEDs. In either method, the average LED current and intensity are reduced in response to the detection of a half wave rectified input current. In this way, the LED signal is "transparent" to the user who may now utilize the LED device in the same manner as conventional
25 incandescent signals.

As shown in the Fig. 5, a half wave power detector circuit **88** has inputs connected to the inputs of the full wave rectifier **32** at the clamp circuit output lines **26** to monitor the input a.c. power on the power input lines **22** to the power supply
10. The detector **88** has an output connected to a control signal line **90** which is
30 connected to an input of the control I.C. **40**. The detector **88** generates a control signal on the line **90** in response to the detection of a half wave dimming signal on the a.c. power lines **22**. The control signal is directed to the power supply

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regulator circuit 38, where it causes the output voltage of the switchmode power supply 10 to be reduced in response to the dimming command. For current regulated power supplies, the average output current to the LED arrays can be reduced to effect dimming. In cases where the LED array is powered by a pulse width modulator, such as the modulator 46, the connection of the line 90 to the control I.C. 40 is eliminated and the output of the detector 88 is connected by a control signal line 92 to an input of the modulator 46 such that the average current delivered to the LED array may be reduced by decreasing the pulse width of the modulator.

All such dimming methods have one key feature in common; the average current through the LED signal 12 is decreased in response to the detection of a half wave dimming signal impressed on the power supply input lines 22. The detection of half wave power by the detector 88 causes the LED power supply 10 to either adjust the output pulse width at constant frequency or adjust the frequency at constant pulse width. The power supply 10 can be any type of power supply which converts a.c. power to d.c. power suitable for illuminating the LED array 12.

The present invention is an apparatus 10 for supplying regulated voltage d.c. electrical power to an LED array including a rectifier means 32 having an input and an output, the rectifier means 32 being responsive to a.c. power at the input for generating rectified d.c. power at the output, a power factor correction converter means 38 having an input connected to the rectifier means 32 output and an output, the power factor correction converter means 38 being responsive to the rectified d.c. power at the power factor correction converter means input for generating regulated voltage, power factor corrected d.c. power at the power factor correction converter means output, and an LED array 12 having an input connected to the power factor correction converter means 38 output for receiving the power factor corrected d.c. power to illuminate the LED array 12. The power factor correction converter means 38 can be a power factor correcting and voltage regulating buck/boost switchmode converter.

The apparatus 10 includes a pulse width modulated modulator means 46 connected to the power factor correction converter means 38 output and the LED

array 12 input for modulating the power factor corrected d.c. power and an electromagnetic interference filter means 28 connected to the full wave rectifier means 32 input for preventing conducted interference from feeding back onto a.c. power lines 22 connected to the rectifier means 32 input. The apparatus 10 also includes an adaptive clamp circuit means 24 connected to the rectifier means 32 input for eliminating leakage current problems. The adaptive clamp circuit means 24 has an input adapted to be connected to a pair of a.c. power lines 22, a pair of clamp circuit output lines 26 connected to the adaptive clamp circuit means 24 input, a voltage sensing means 48 connected across the adaptive clamp circuit means 24 input, and a controlled load means 50 connected across the clamp circuit output lines 26 and to the voltage sensing means 48. The voltage sensing means 48 is responsive to a magnitude of a.c. voltage at the adaptive clamp circuit means 24 input lower than a predetermined magnitude for turning on the controlled load means 50 to connect a low impedance load 60 in the controlled load means 50 across the clamp circuit output lines 26 and the voltage sensing means 48 is responsive to a magnitude of the a.c. voltage at the adaptive clamp circuit means 24 input equal to or greater than the predetermined magnitude for turning off the controlled load means 50 to disconnect the low impedance load 60 from the clamp circuit output lines 26.

The apparatus 10 further includes a battery backup means 62 having an input for receiving a.c. power applied to the rectifier means 32 input and having an output at which d.c. power is generated, and a switch-over means 82 connected to the battery backup means 62 output and to the rectifier means 32 input, the battery backup means 62 being responsive to a failure of a.c. power at the battery backup means 62 input for controlling the switch-over means 82 to connect the battery backup means 62 output to the rectifier means 32 input to provide d.c. power to illuminate the LED array 12 and being responsive to a.c. power at the battery backup means 62 input for controlling the switch-over means 82 to disconnect the battery backup means 62 output from the rectifier means 32 input. The switch-over means 82 can be an electromechanical relay. The battery backup means 62 includes a time delay and restoration means 78 responsive to application of a.c. power at the battery backup means 62 input for controlling the switch-over means

82 to disconnect the battery backup means 62 output from the rectifier means 32 input and connect the a.c. power to the rectifier means 32 input after a predetermined time delay. The battery backup means 62 also includes a d.c. power switch-over and flasher means 80 connected to the switch-over means 82 for
5 pulsing the d.c. power at a predetermined rate to flash the LED array 12 and a synchronizing pulse generator means 86 connected to the d.c. power switch-over and flasher means 80 for imposing marker pulses on the d.c. power at a predetermined rate.

The apparatus 10 also includes a half wave power detector means 88 having
10 an input connected to the input of the rectifier means 32 and an output connected to another input of the power factor correction converter means 38, the half wave power detector means being responsive to a dimming signal at the rectifier means input for generating a control signal at said half wave power detector means output and the power factor correction converter means 38 being responsive to the control
15 signal for decreasing the regulated d.c. power to dim the LED array 12. If the apparatus 10 includes the pulse width modulated modulator means 46 connected to the power factor correction converter means 38 output and the LED array 12 input for modulating the regulated voltage d.c. power, the half wave power detector means 88 has its output connected to an input of the pulse width modulated
20 modulator means 46 and is responsive to a dimming signal at the rectifier means input for generating a control signal at the half wave power detector means output and the pulse width modulated modulator means 46 is responsive to the control signal for decreasing the regulated d.c. power to dim the LED array 12.

In accordance with the provisions of the patent statutes, the present invention
25 has been described in what is considered to represent its preferred embodiment. However, it should be noted that the invention can be practiced otherwise than as specifically illustrated and described without departing from its spirit or scope.